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Characteristic changes of the pre-ejection period of the human fetal heart during umbilical cord complications

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1 Introduction

A differential analysis of the cardiotocogram allows conclusions as to the functional state of the fetus. However, the interpretations of changes in the heart rate depend to a large extent on the experience of the examiner because of the poorly defined deliminations of specific patterns of heart rate changes. New techniques enable the recording of the pre-ejection period (PEP) of the human fetal heart; i.e., the time between ventricular excitation and aortic pressure rise, continuously parallel with the CTG [3, 12, 16, 24, 27]. The PEP is a measure of the myocardial contractility. Thus, with adrenergic stimulation the cardiac contractility increases and the PEP is shortened. On the other hand, an increase in peripheral resistance leads to a lengthening of the PEP as does a decrease of ventricular filling. Recent experiments in fetal lambs [20, 21, 37, 52, 53] showed in acute and chronic experiments [20, 29] that in acute hypoxia the PEP falls below the normal range, and that with compression the PEP is increased while the relation of the PEP to duration of systole (relative PEP = PEPr) is constant. Furthermore, with umbilical cord complications characteristic PEP changes are seen and chronic and acute hypoxia lead to changes in the baseline level of the PEP. This study deals with the question whether the results of animal experiments from PEP recording together with the CTG apply to the human fetus during birth and whether the characteristics of the PEP and heart rate allow conclusions as to the pathophysiology of umbilical cord complications.

Curriculum vitae

THOMAS BÄRTLING *was born in 1947 in Bad Harzburg – Germany. He studied medicine at the University of Cologne from which he was graduated 1974. In 1972 und 1973 he worked at Cardiopulmonary - Physiology - Laboratories, Dep. Anaesthesiology at the University of Cologne. Since 1975 he is working in the Dep. Obstetrics and Gynecology, faculty of medicine of the Rheinisch-Westfälische-Technische-Hochschule Aachen. Main fields of interests: Cardiopulmonary system, fetal circulation, fetal monitoring, intensive care.*

2 Material and method

During the delivery of 115 fetuses the course of the absolute and relative PEP was recorded for at least 50–90 minutes simultaneously with the CTG. Of the 115 fetuses, 38 had a nuchal umbilical cord noted at birth. The CTG and PEP recordings of these 38 fetuses are the subject of the study. During or shortly after PEP recording a blood sample was obtained from the fetal scalp for the analysis of pH, base excess and pCO_2. Blood gas analysis from umbilical artery blood was performed immediately postpartum. In five fetuses with documented cord complication the transcutaneous oxygen tension was recorded from the presenting part according to the method of HUCH [28, 29, 30] and recorded together with the PEP and

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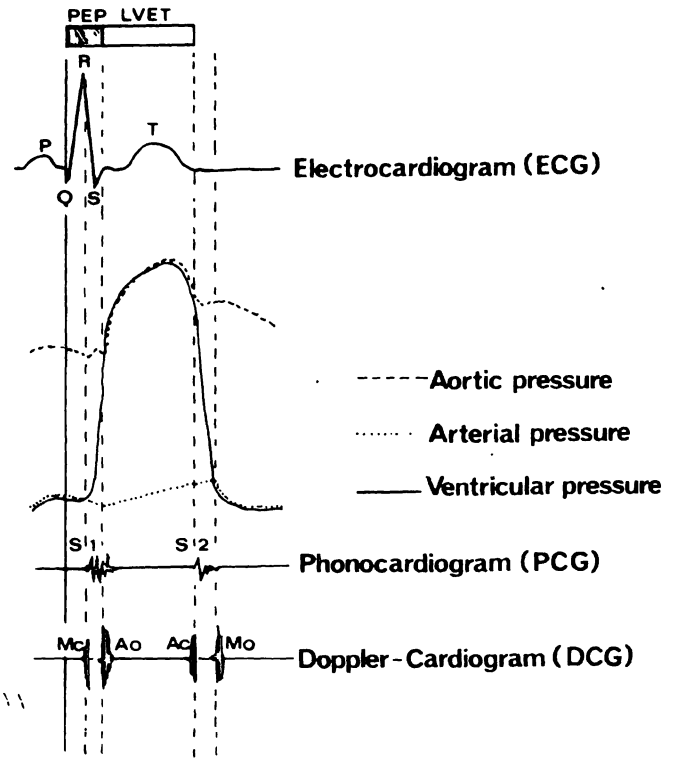

Fig. 1. Systolic time intervals: S1, (2): first and second heart tones. Mc = mitral valve close, Mo = mitral valve opening, Ac = aortic valve closure.
PEP = pre-ejection period (PEPa = absolute PEP, PEPr = relative PEP).
LVET = left ventricular ejection time.
Preload (EDV) = end-diastolic ventricular pressure.
Afterload (DAP) = diastolic arterial pressure.

CTG on a polygraph. The PEP is defined as the time between ventricular excitation and the ventricular ejection; i.e., the time between the R and Q wave in the fetal ECG and the pressure rise in the aorta or the opening of the aortic valve (Fig. 1). The PEP was measured by a conventional cardiotocograph (Hewlett Packard 8030A) and an additional signal processor which we developed in collaboration with the manufacturer. The trigger signals for the electronic calculation of the absolute PEP are the R wave in the fetal ECG recorded from a scalp electrode as well as the opening of the aortic valve recorded with a DOPPLER monitor from the mother's abdomen. Thus, we were able to record the PEP continuously online and beat-to-beat in the pressure channel of one of the two instruments parallel with the CTG. The aortic and mitral valves can be differentiated with an oscillograph or by means of an electronic time "window". These methods are described in more detail in a previous work [3]. Intrauterine pressure was recorded conventionally with an indwelling catheter and a pressure transducer. In order to determine relative PEP, i.e., the ratio of the absolute PEP to the total cardiac cycle, necessary signals were recorded on a four channel magnetic tape recorder (Hewlett Packard) and subjected to off-line digitization for calculation by microprocessor and subsequent output for the recorder of the absolute and relative PEP time. The calculation of the relative PEP makes possible the recognition of PEP changes which are depended upon the heart rate [5]. In heart rate dependent PEP changes the relative PEP does not change.

$$\text{PEP relative } \% \frac{\text{PEP absolute (msec)} \times 100}{\text{cardiac cycle (mec)}}$$

3 Results

The 38 fetuses with umbilical cord complications documented after birth showed during labor contractions quite varying changes in fetal heart rate: 17 (45%) of the fetuses responded to umbilical cord ompression during contraction with a deceleration of the acceleration-deceleration type (AD-Dip); 7 (18%) of the fetuses responded with a type I Dip and another 7 with acceleration. Fifteen (39%) fetuses reacted to the increased intrauterine pressure with mild to severe variable decelerations and two fetuses with a type II Dip. Two or more different types of heart rate changes during contractions while PEP was measured occurred in 12 fetuses (32%). Only one fetus with cord complication demonstrated no change of the heart rate pattern during contraction (Fig. 2).

The course of the PEP during contraction in fetuses in postpartum documented cord complications showed four characteristic patterns (a) a monophasic increase of the PEP during the contraction; (b) a monophasic decrease of the PEP; (c) a biphasic PEP pattern with initial lengthening and subsequent shortening below the mean PEP time; (d) a double monophasic PEP increase in two steps. In contrast to various patterns in heart

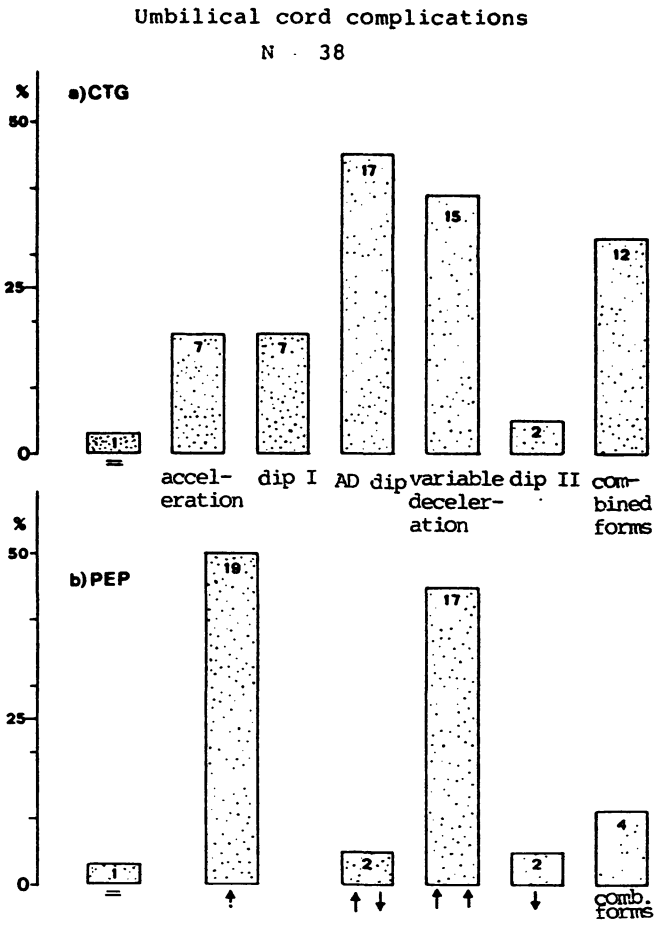

Fig. 2. CTG changes and PEP changes in fetuses with umbilical cord complication =: no changes. Akz: acceleration. AD-Dip: heart rate changes of the acceleration/deceleration. Komb: combination of various patterns.
↑ Monophasic PEP rise.
↑↑ Biphasic PEP rise.
↓ PEP decrease.
↑↓ Initial PEP rise with subsequently PEP decrease.

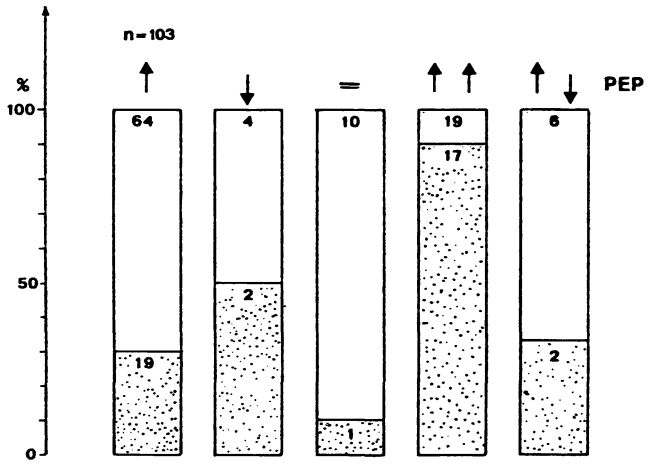

Fig. 3. Proportion of fetuses with cord complications (dark areas) in various PEP patterns in correlation with heart rate changes during contractions. See Figure 2 for explanation of symbols.

rate changes with cord compression during contraction the pattern of the PEP is more uniform since only one fetus showed no PEP changes at all. A simple monophasic prolongation of the PEP during uterine contractions was seen in 19 (50%) of the fetuses, a two-step increase in PEP was seen in 17 (45%) of the fetuses (Figs. 4, 5, 6). Only two fetuses (6%) had a biphasic PEP pattern with initial prolongation and subsequent shortening below the baseline PEP time. Both fetuses who had late decelerations in the cardiotocogram showed consistently a shortening of the PEP during contractions. Only four fetuses presented with combinations of two or more different PEP patterns (Fig. 6). Thus, cord complications almost always lead to a one-step or two-step prolongation of the PEP; these two patterns may be combined (Fig. 5).

Among all patients examined (N = 115) 103 fetuses demonstrated heart rate changes during contractions. A comparison of the PEP patterns seen in fetuses with cord complications with those seen in the remainder of the patients examined who had heart rate changes (Fig. 3) shows that 89% of the fetuses with double monophasic PEP rise in two steps has documented cord complications while the proportion of cord complications (dark pattered areas in Fig. 3) to the remaining PEP patterns in the entire group of patients is much lower.

The changes in the absolute PEP described above in fetuses with cord complications remain apparent when the relative PEP is calculated; i.e., in addition to the change in the absolute PEP the proportion of the PEP to the cardiac cycle is changed (Fig. 6). The PEP changes during contraction thus are independent of changes in the fetal heart rate. In the case illustrated in Fig. 6, during the first and fourth contraction there is a slight decrease in the fetal heart rate and a slight prolongation of the absolute PEP while, in these two contractions the relative PEP remains constant. These mild changes during the first and fourth contraction are therefore solely due to the change in the mean heart rate while the proporation of the PEP to the cardiac cycle remains constant. In the remaining contractions, however, there is a change in the absolute as well as relative PEP in relation to the

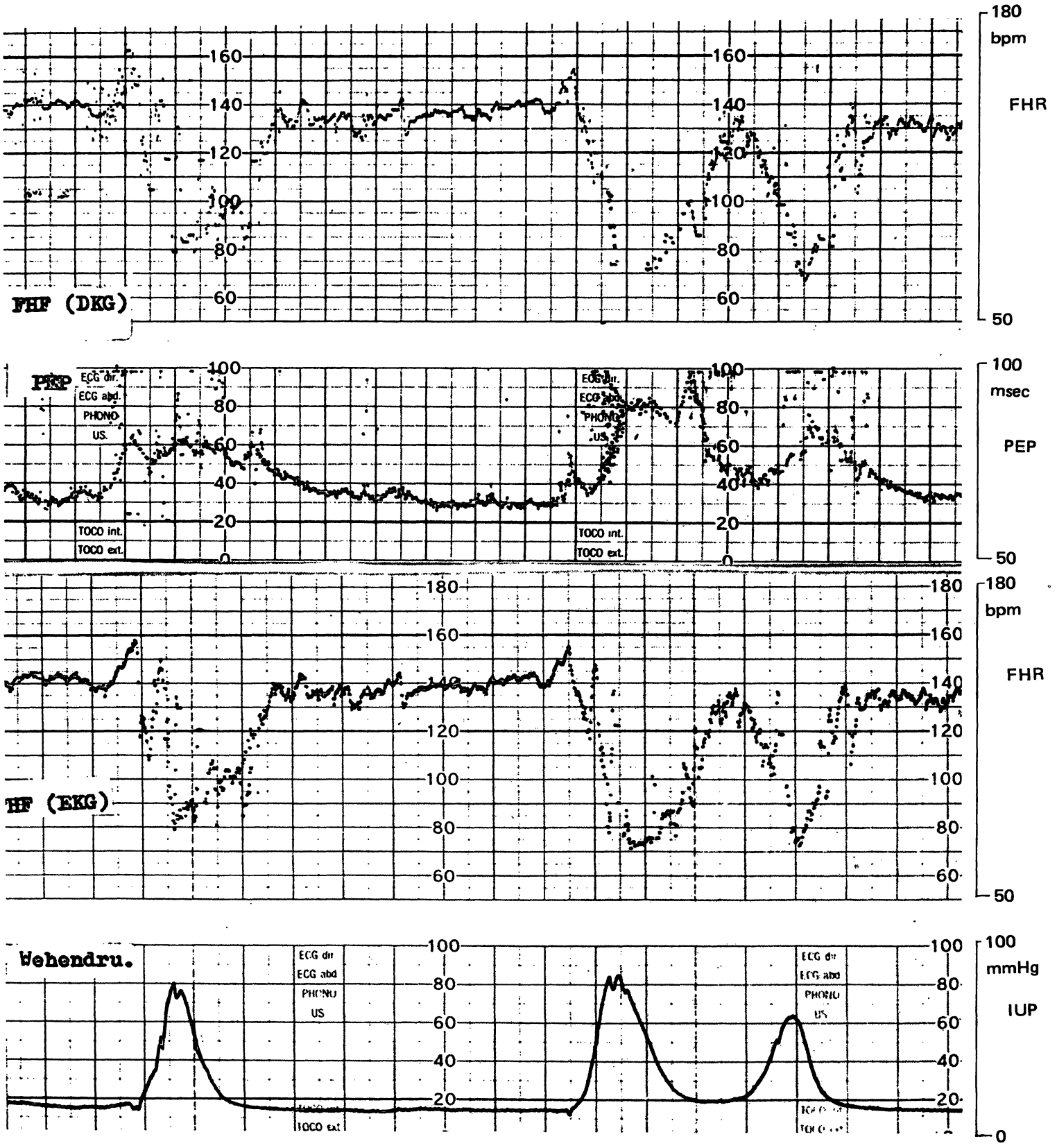

Fig. 4. Original record of intrauterine pressure (IUP). During the second contraction with a variable deceleration there is a characteristic biphasic PEP rise while there is only a monophasic PEP rise during the third contraction.

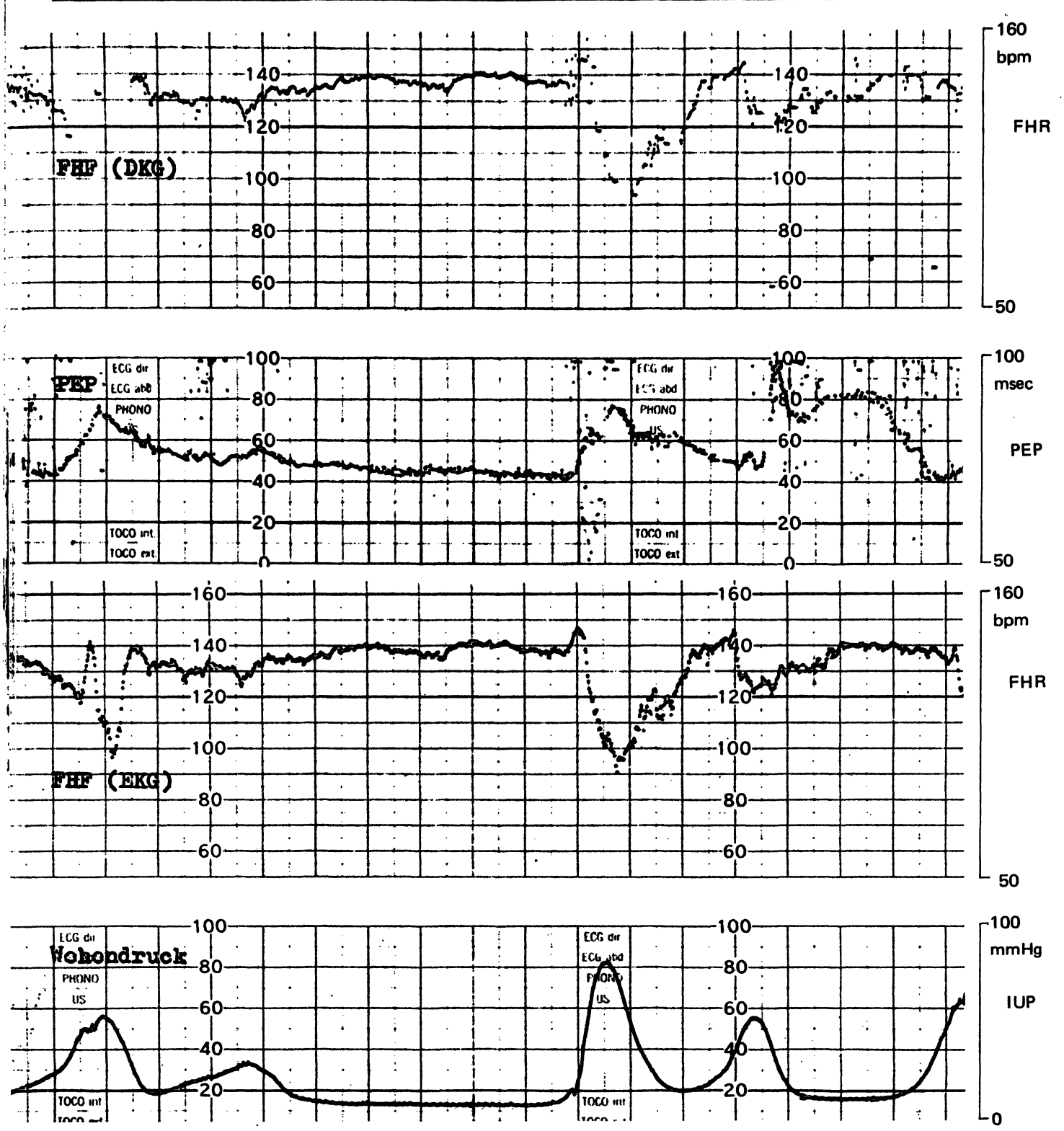

Fig. 5. Original traching of multi-step PEP rises during cord occlusion.

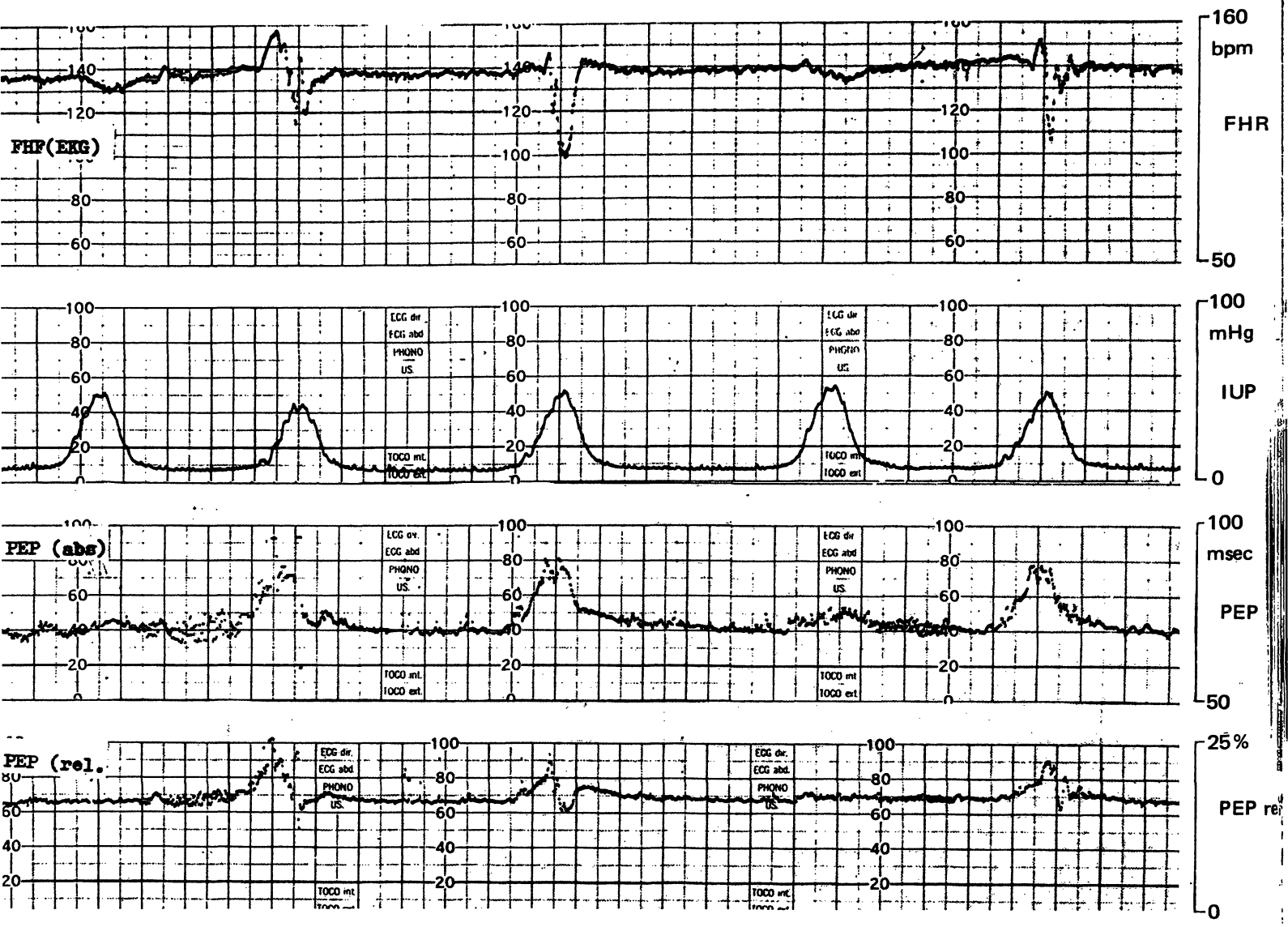

Fig. 6. Characteristic changes of absolute and relative PEP in cord compression with various patterns of heart rate changes.

patterns of deceleration, i.e., the proportion of the absolute PEP to the cardiac cycle is also changed.

The PEP patterns characteristic for cord complications do not corrrelate with blood gas analysis obtained during and after birth. We observed these PEP courses in fetuses with a normal acid base balance as well as in those with pre-acidotic blood gas values. Similarly, the characteristic PEP patterns do not correlate with transcutaneous oxygen tension. However, during contraction there is almost always a relative increase of transcutaneous oxygen tension. In most incidents of fetal cord complication there is a single or double increase in PEP during contractions. The values of the APGAR score and the PEP pattern do also not correlate.

4 Discussion

These results as well as earlier investigations by others [11, 22, 36] show that cord compression may lead to quite different patterns of heart rate changes in different fetuses. Fetuses with cord complication usually had decelerations of the AD type or variable decelerations as well as a combina-

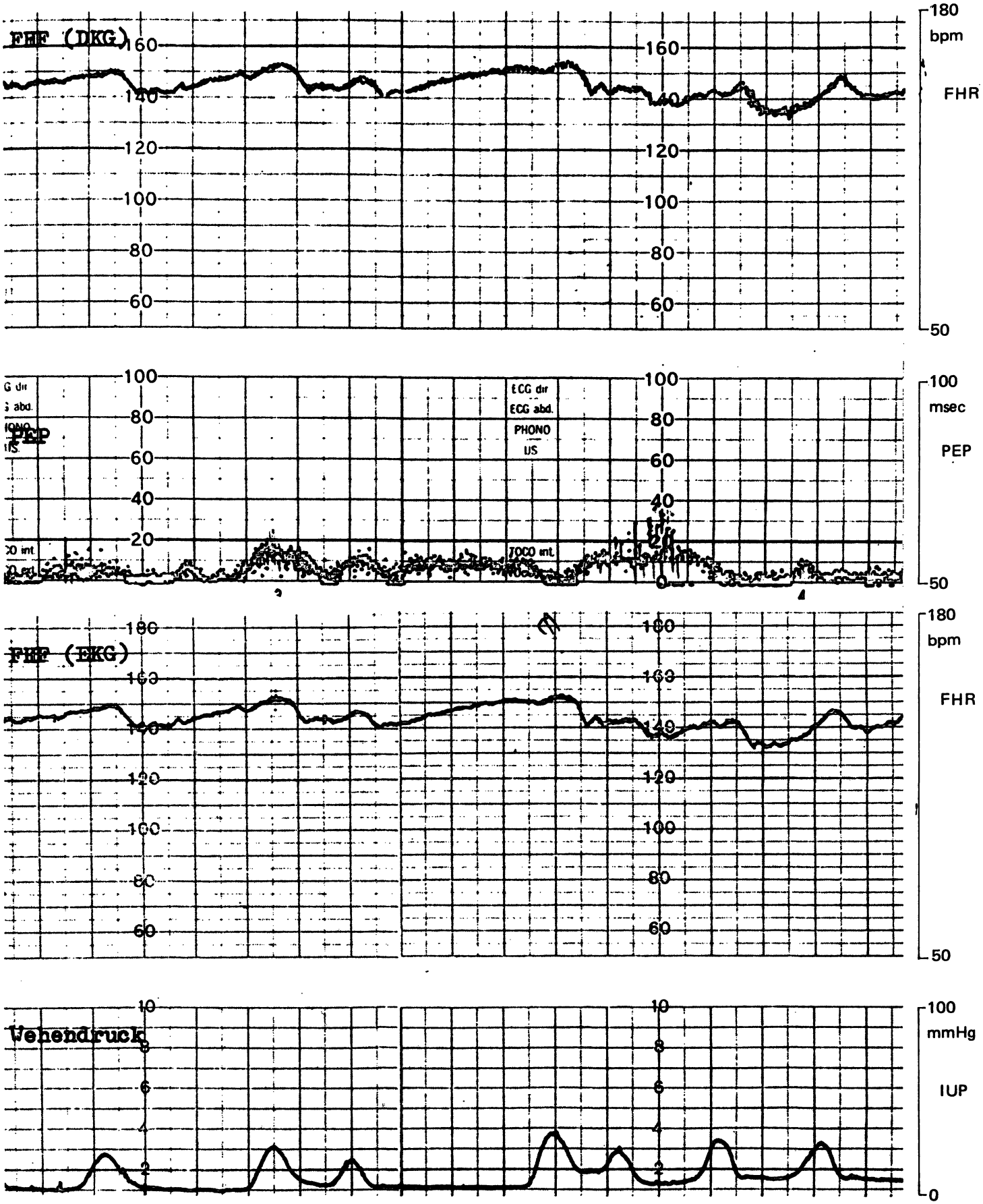

Fig. 7. PEP pattern in late deceleration and silent oscillation pattern in the CTG. The baseline PEP is shorter than the normal range (65–80 msec).

tion of various patterns of deceleration. However, in almost all fetuses the absolute and relative PEP increase during contraction either as a monophasic PEP increase or as a dual monophasic PEP pattern with a second step in addition to the initial increase. A double monophasic PEP increase appears to be characteristic for cord complications; 89% of all fetuses in our material with heart rate changes during the contraction (N = 103) who had a two-step type PEP increase had a documented cord complication. This second rise in PEP following an initial rise has been observed by EVERS and DE HAAN [20, 21] in chronic sheep experiments with poorly oxygenated fetal lambs (e.g., Figures 4 and 5). EVERS and DEHAAN [20, 21] demonstrated that the second PEP rise is caused by a second increase in arterial blood pressure. If the alpha-adrenergic receptors in the fetal lamb were blocked with phentolamine the second rise in blood pressure and PEP was not observed. In the contrary, both PEP as well as blood pressure fell during the second half of the umbilical cord occlusion. The initial step of the PEP rise during the concentration is probably due to the sudden hemodynamic changes caused by the cord compression, namely increased afterload (DA) and decreased preload (EDVP). As has been shown in the chronic sheep experiments the second step-up is due to an additional increase of the afterload because of peripheral vasoconstriction induced by chemoreceptor reflex. According to EVERS and DEHAAN the interval between the first and second PEP rise correlates positively with the oxygen saturation of the fetal blood at the time of the occlusion; i.e., the longer the interval between the two PEP rises the better oxygenation of the fetal blood. However, the second PEP rise was only observed in poorly oxygenated fetal lambs. This phenomenon was not observed in this the present study in human fetuses during birth. Intermittent measurements of pO_2 and acid base balance did not establish correlations between the second rise in PEP and partial pressure of oxygen or pH in the fetal blood pH. Similarly, a comparison of the transcuteneous oxygen tension of the fetal scalp did not establish a relation of the partial pressure of oxygen and the second PEP longation because as demonstrated in our own work [7] and by HUCH [29] during contractions there is a relative increase of the transcutaneous oxygen tension of the fetal scalp. Possible mechanisms for this phenomenon have been discussed elsewhere [7].

SCHMIDT and MORGENSTERN [37, 52, 53] observed in umbilical cord compression in acute sheep experiments an increase in the heart minute volume (HMV) and a different PEP pattern; In the acute experiment the cord compression led to an excessive prolongation of the PEP which was constant even with the determination of the relative PEP and thus was not due to a decrease in fetal heart rate during deceleration. The independence of PEP changes from the fetal heart rate in fetuses with cord complications was also demonstrated in the current study in as much that during deceleration and other heart rate changes there was a change of the absolute as well as the relative PEP. In addition SCHMIDT and MORGENSTERN observed in acute experiments in some cases of umbilical cord occlusion a secondary PEP drop after an initial rise. This PEP pattern was also seen by EVERS and DEHAAN during mild cord occlusion and after the blockage of chemoreceptors with Phentolamine. We observed in the human fetus this PEP pattern usually only with deceleration of the acceleration-deceleration type (AD-type Dip) as well as with accelerations. Only in one case serious variable decelerations were seen together with this type of PEP pattern. A inter-relation of PEP and preload and afterload was also shown by MURATA [39, 40, 42, 44] in chronic experiments with fetal rhesus monkeys. In these animal experiments which used the same methodology as used by us, the PEP correlated negatively with preload and positively with afterload. Similar to our own findings, MURATA's animal experiments did not demonstrate a direct correlation between oxygen tension and PEP.

Thus, we conclude that certain important findings from animal experiments may be transferable to the human fetus during birth [5, 6, 7, 12, 46, 48]. The determination of absolute and relative PEP simultaneously with CTG apparently makes possible a more detailed assessment of the state of the fetus during certain types of deceleration.

Summary

In 38 fetuses with postpartum documented cord complications the pre-ejection period was recorded continuously with a new measuring methodology on-line parallel with the cardiotocogram (CTG). With the aid of this method PEP can be recorded in the human fetus during delivery over longer periods of time. The recording of the PEP and calculation of relative PEP allows information on the state of the fetus during birth beyond the capabilities of the CTG alone. A comparison of the PEP pattern with the course and decelerations in the cardiotocogram makes it possible to grade various deceleration patterns as to their clinical importance. Our 38 fetuses had blood gases determined before and immediately after birth from the fetal scalp and umbilical artery respectively. In an additional five fetuses the transcutaneous pO_2 tension was also recorded continuously from the presenting part parallel with the other variables.

Methods: The PEP was measured with a conventional Hewlett Packard cardiotocograph and a signal processor from the same manufacturer. The fetal EKG signals recorded from scalp electrode served as trigger signals for the electronic calculation of the PEP as well as the opening of the aortic valve as recorded with a Doppler instrument from the maternal abdomen. From these variables the absolute PEP was calculated on-line and recorded parallel with the CTG. In addition the relative PEP was calculated off-line; i.e., a determination of the proportion of the PEP to the total cardiac cycle. This was also recorded relative to the PEP and the CTG. The recording of transcutaneous oxygen tension followed the method of Huch and blood gases were determined with a Radiometer instrument.

Results: PEP changes depend on preload and afterload, blood pressure and ventricular filling. They indicate changes in the myocardial contractility caused by normal or pathologic changes in the fetal-placental system. Of a total of 115 fetuses 103 had heart rate changes during labor contractions. They had four different characteristic patterns of the PEP: (1) a monophasic prolongation of the PEP during a contraction; (2) a monophasic shortening of the PEP during contractions; (3) a biphasic PEP rise with initial prolongation and subsequent shortening below the baseline PEP time; (4) a dual monophasic PEP rise in two steps. Fetuses with documented cord complication (N = 38) almost always had a monophasic or two-phasic increase in the absolute PEP and a similar pattern of the relative PEP during contractions, whereas the heart rate patterns may be quite inconsistent. One and two-phase PEP rises were often seen in the same fetus. A dual monophasic PEP increase appears to be characteristic for cord compression. 89% of all fetuses with two-step PEP rises had a cord compression. There is no correlation of the PEP pattern and the partial pressure of oxygen or fetal acid base balance. The measurement of absolute and relative PEP parallel with the CTG may help in the interpretation of deceleration of patterns in clinical practice.

Keywords: Cardiography, fetal circulation, fetal monitoring, systolic time intervals, umbilical cord complications.

Zusammenfassung

Charakteristische Veränderungen der Pre-ejection-Periode des menschlichen fetalen Herzens bei Nabelschnurkomplikation

Bei 38 Feten mit postpartual sichtbarer Nabelschnurumschlingung wurde unter der Geburt die Pre-ejection-Periode mit einem neuen Meßverfahren kontinuierlich online parallel zum Kardiotokogramm registriert. Mit dieser Meßmethodik kann die PEP beim menschlichen Feten unter der Geburt über einen elängeren Zeitraum kontinuierlich aufgezeichnet werden. Durch Registrierung der PEP und Berechnung der relativen PEP ist es möglich, über das CTG hinausgehende Informationen über den Zustand des Feten unter der Geburt zu erhalten, und es ist durch Vergleich des PEP-Verlaufes mit dem Dezelerationsverlauf im Kardiotokogramm möglich, bestimmte Dezelerationsformen in ihrer klinischen Wertigkeit abzustufen. Zusätzlich erfolgte bei allen 38 Feten eine punktuelle Blutgasanalyse aus der fetalen Kopfhaut während der Maßperiode sowie unmittelbar post partum aus der Nabelarterie. Bei 5 Feten wurde zusätzlich die transkutan am vorangehenden Teil gemessene pO_2-Spannung kontinuierlich parallel zu den oben genannten Parametern registriert.

Methodik: Die Messung der PEP wurde mit einem konventionellen Kardiotokographen von Hewlett & Packard und einem Signalverarbeitungsgerät der gleichen Firma durchgeführt. Als Triggersignale für die elektronische Berechnung der PEP diente das EKG, welches über eine Skalpelektrode abgeleitet wurde sowie die Eröffnung der Aortenklappe, die mit dem Dopplerprinzip über dem Abdomen der Kreißenden erfaßt wurde. Aus diesen Parametern wurde die absolute PEP on-line berechnet und parallel zum CTG aufgezeichnet. Zusätzlich wurde off-line eine Bestimmung der relativen PEP, d.h. eine Bestimmung des prozentualen Anteils der PEP an der Herzperiodendauer durchgeführt und diese ebenfalls parallel zur absoluten PEP und zum CTG aufgezeichnet. Die Registrierung der transkutanen Sauerstoffspannung erfolgte nach dem HUCH'schen Prinzip, die intrapartualen und postpartualen Blutgasanalysen wurden mit einem Radiometer-Blutgasanalyse-Gerät ermittelt.

Ergebnisse: Veränderungen der PEP hängen von Preload und Afterload, Blutdruck und Ventrikelfüllung ab und zeigen Veränderungen in der Kontraktilität des Myocards an, die durch normale oder pathologische Veränderungen der Stellgrößen im feto-plazentaren System bedingt sind. Im Gesamtkollektiv (n = 115 Feten) wurden im Zusammenhang mit Herzfrequenzalterationen in der Wehe (n = 103 Feten) 4 verschiedene charakteristische Verläufe der PEP beobachtet: 1. eine monophasische Ver-

längerung der PEP während der Wehe. 2. eine monophasische Verkürzung der PEP. 3. ein biphasischer PEP-Verlauf mit initialer Verlängerung und anschließender Verkürzung unter die basale PEP-Zeit. 4. ein doppelt-monophasischer PEP-Anstieg in 2 Stufen. Bei Feten mit postpartal sichtbarer Nabelschnurkomplikation (n = 38) kommt es fast immer zu einem entweder einphasigen oder zweiphasigen Anstieg der absoluten PEP und einem gleichsinnigen Verlauf der relativen PEP während der Wehe, während völlig verschiedene Herzfrequenzalterationsmuster vorliegen können. Oft werden 1- und 2-phasige PEP-Anstiege bei einem Feten gleichzeitig beobachtet. Charakteristisch für eine Nabelschnurkomplikation scheinen doppelt-monophasische PEP-Anstiege zu sein. Bei 89% aller Feten mit 2-stufigen PEP-Anstiegen im Gesamtkollektiv konnte post partum eine Nabelschnurkomplikation nachgewiesen werden. Eine Abhängigkeit des jeweiligen PEP-Verlaufes in der Wehe vom Sauerstoffpartialdruck respektive Säurebasenhaushalt des Feten wurde in diesem Kollektiv nicht beobachtet. Durch Messung von absoluter und relativer PEP parallel zum CTG scheint es möglich zu sein, verschiedene Dezelerationsmuster in ihrer klinischen Wertigkeit besser interpretieren zu können.

Schlüsselwörter: Fetaler Kreislauf, fetale Überwachung, Kardiotokographie, Nabelschnurkomplikation, systolische Zeitintervalle.

Résumé

Modifications charactéristiques de la période pré-éjectionnelle du coeur foetal humain en cas de complications ombilicales.

L a période pré-ejectionnelle (PEP) a été enregistrée on-line parallèlement au cardiotocogramm à l'aide d'un nouveau procédé d'enregistrement pendant l'accouchement de 38 nouveau-nés qui présentaient des circulaires du cordon post-partum. A l'aide de ce procédé il est possible d'enregistrer la PEP de façon continue pendant l'accouchement et durant un long laps de temps. Il est possible d'obtenir des informations supérieures au CTG sur l'état de l'enfant pendant l'accouchement à l'aide de l'enregistrement de la PEP et le calcul de la PEP relative; à l'aide la comparaison entre le tracé PEP et celui des décélérations cardiotocographiques il est possibe d'apprécier la valeur clinique de certaines formes de décélérations. Nous avons en plus éffuctué l'analyse des gas du sang au scalp foetal pendant la période d'enregistrement ainsi qu'immédiatement post partum dans l'artère ombicale. Parallèlement à ces paramètres, la PO2 a été enregistrée de façon continue et transcutanée au niveau de la présentation de 5 foetus.

Méthodes: La mesure de la PEP a été effectuée à l'aide d'un cardiotocographe conventionnel de Hewlett & Packard ainsi qu'avec un appareil de traitement du signal de la même maison. L'ECG servait en tant que signal Trigger pour le calcul électronique de la PEP; il était enregistré au scalf foetal. Il en était de même de l'ouverture de la valve aortique qui était enregistrée selon le principe Doppler sur l'abdomen de la patiente. La PEP absolue a été calculée à partir ce ces paramètres on-line et a été enregistrée parallèlement au CTG. En outre nous avons déterminé off-line la PEP relative, c'est-à-dire le pourcentage de la PEP sur la durée de la période cardiaque, et nous l'avons egalement rapportée à la PEP absolue et au CTG. L'enregistrement de la tension transcutanée d'oxygène s'éffectuait selon le principe de HUCH, les analyses intra et postpartales de gas du sang ont été réalisées à l'aide d'un appareil Radiometer.

Résultats: Les variations de la PEP dépendent du Preload, du Afterload, de la tension sanguine et du remplissage ventriculaire et montrent des changements dans la contractilité du myocarde qui sont pruduites par des variations normales ou pathologiques dans le système foetoplacentaire. Dans l'ensemble du collectif (n = 115 foetus) nous avons observé 4 tracés charactéristiques de la PEP en relation avec des altérations de la fréquence cardiaque pendant la contraction (n = 103 foetus): 1.- un allongement monophasique de la PEP pendant la contraction; 2.- un raccoucissement monophasique de la PEP; 3.- un tracé biphasique de la PEP avec un allongement initial suivi de raccourcissement en dessous du temps basal de PEP; 4.- une augmentation doublement monophasique de la PEP en deux temps. Chez les foetus qui présentaient des circulaires du cordon à la naissance (n = 38), il survient pratiquement toujours une augmentation soit monosoit biphasique de la PEP absolue ainsi qu'un tracé de même sens de la PEP relative pendant la contraction, alors que des tracés d'altérations complètement différents peuvent être enregistrés. L'on observe fréquemment simultanément des augmentations mono- et biphasiques chez le même foetus. Les augmentations doublement monophasiques semblent être charactéristiques pour des circulaires du cordon. Une telle circulaire a été observée chez 89! des foetus ayant présenté des augmentations de PEP en deux temps. Il n'a pas été noté de relation entre les tracés PEP respectifs durant la contraction et la préssion partielle d'oxygène ou les valeurs de l'équilibre acido-basique du foetus. Il semble qu'il soit possible de mieux interpréter au point de vue clinique des divers tracés de décélérations à l'aide de la mesure de la PEP relative et absolue en rapport avec le CTG.

Mots-clés: Cardiotocographie, circulation foetale, complications funiculaires, intervalle de temps systolique, surveillance foetale.

Bibliography

[1] ASSALI, N. S., C. R. BRINKMAN, B. NUWAYHID: Comparison of maternal and fetal cardiovascular functions in acute and chronic experiments in the sheep. Amer. J. Obstet. Gynec. 120 (1974) 411

[2] BÄRTLING, TH., B. LIEDTKE, F. K. KLÖCK: Die PEP-Zeit im Rahmen der Neugeborenenüberwachung. SCHMIDT, E., J. W. DUDENHAUSEN (Eds.): Perinatale Medizin, Bd. VII, Thieme, Stuttgart 1978

[3] BÄRTLING, TH., F. K. KLÖCK, E. COURTIN: Ein neues Verfahren zur on-line Registrierung der Pre-ejection-period des menschlichen fetalen Herzens parallel zum CTG. Z. Geburtsh. u. Perinat. 182 (1978) 178

[4] BÄRTLING, TH., F. K. KLÖCK: The pre-ejection-period of the human fetal heart. Patterns of change during labour and decelerations. 6th. European Congr. Perinat. Med. Vienna (A), 1978

[5] BÄRTLING, TH., F. K. KLÖCK: Die Pre-Ejection-Period des menschlichen fetalen Herzens: Bedeutung der Base-Line-Schwankung in der Perinatalperiode. Z. Geburtsh. u. Perinat. 183 (1979) 202

[6] BÄRTLING, TH., F. K. KLÖCK: Die Pre-Ejection-Period des menschlichen und fetalen Herzens: Veränderungen in der Wehe und bei verschiedenen Dezelerationsmustern. Z. Geburtsh. u. Perinat. 183 (1979) 405

[7] BÄRTLING, TH., F. K. KLÖCK, B. LIEDTKE: Vergleichende Untersuchung von Pre-Ejection-Period und transkutan gemessener Sauerstoffspannung unter der Geburt. Z. Geburtsh. u. Perinat. 183 (1979) 419

[8] BÄRTLING, TH.: Monitoring of fetal systolic time intervals as a parameter of hemodynamic changes in the fetal cardiovascular system sub partu. International Meeting of Perinatal Medicine (in print)

[9] BÄRTLING, TH., F. K. KLÖCK, B. LIEDTKE: Vergleichende Untersuchung von Pre-ejection-period und transkutan gemessener Sauerstoffspannung in der Neugeborenenperiode. Z. Geburtsh. u. Perinat. 184 (1980) 31

[10] BERG, D.: Continuously measured fetal oxygen pressures and beat-to-beat rate in fetal lambs and their modification via the mother (hypoxia, placental ischämia, drugs). In: BOSSARD, H., J. M. CRUZ, A. HUBER, L. S. PROD'HOM, J. SISTEK (Eds.): Perinatal Medicine. Huber, Bern 1973

[11] BERG, D., A. HUCH, R. HUCH, J. SCHULZ, K. WERNICKE: Zur Genese von späten Decelerationen der fetalen Herzfrequenz. Arch. Gynäk. 214 (1973) 425

[12] BERNSTEIN, A., L. W. ORGAN, L. E. EISNER, K. C. SMITH, I. H. ROWE: Measurement of the pre-ejection-period during labor with the use of arterial pulse time. Amer. J. Obstet. Gynec. 126, 2 (1976) 238

[13] COHN, H. E., E. J. SACKS, M. A. HEYMANN, A. M. RUDOLPH: Cardiovascular responses to hypoxemia and acidemia in fetal lambs. Amer. J. Obstet. Gynec. 120 (1974) 817

[14] COMLINE, R. S., M. SILVER: The release of adrenaline and noradrenalin from the adrenal glands of the fetal sheep. J. Physiol. 156 (1961) 424

[15] COMLINE, R. S., I. A. SILVER, M. SILVER: Factors responsible for the stimulation of the adrenal medulla during asphyxia in the fetal lamb. J. Physiol. 178 (1965) 211

[16] COUSIN, A. J., K. C. SMITH, I. H. ROWE, L. W. ORGAN: A cardiac pre-ejection-period monitor for fetal assessment during labor. Medical and Biological Engineering (1974) 479

[17] DAWES, G. S., J. C. MOTT, H. J. SHELLEY: The importance of cardiac glycogen for the maintenance of life in foetal lambs and newborn animals during anoxia. J. Physiol. 146 (1959) 516

[18] DAWES, G. S., B. V. LEWIS, J. E. MILLIGAN, M. R. ROACH, N. S. TALNER: Vasomotor responses in the hind limbs of foetal and newborn lambs to asphyxia and aortic chemoreceptor stimulation. J. Physiol. 195 (1968) 55

[19] DAWES, G. S., S. L. DUNCAN, D. V. LEWIS, C. L. MERLET, J. B. OWEN-THOMAS, J. T. REEVES: Hypoxemia and aortic chemoreceptor function in foetal lambs. J. Physiol. 201 (1969) 105

[20] EVERS, J. L. H., J. DE HAAN, H. W. JONGSMA, J. A. CREVELS, T. H. M. ARTS: The pre-ejection-period of the fetal cardiac cycle in the chronic sheep experiment. In: SCHMIDT, E., J. W. DUDENHAUSEN, E. SALING (Eds.): Perinatale Medizin, Bd. VII. Thieme, Stuttgart 1978

[21] EVERS, J. L. H.: The cardiac pre-ejection period during prenatal life. Thesis. Catholic university, Nijmegen 1978

[22] FISCHER, W. M., H. BRANDT, S. FRITZ: Über die Korrelation biochemischer Parameter des mütterlichen und fetalen Blutes und Herzfrequenzalterationen des Feten. Arch. Gynäk. 214 (1973) 430

[23] GOODLIN, R. C., J. GIRARD, A. HOLLMEN: Systolic time intervals in the fetus and neonate. Obstet. and Gynec. 39 (1972) 295

[24] GOODLIN, R. C., E. W. LOWE: Multiphasic fetal monitoring. Amer. J. Obstet. Gynec. 119 (1974) 341

[25] HAAN, J. DE, C. B. MARTIN, J. L. H. EVERS, H. W. JONGSMA: Pathophysiologic mechanisms underlying fetal heart-rate patterns. In: THALHAMMER, O., K. BAUMGARTEN, A. POLLAK (Eds.): Perinatal Medicine. Thieme, Stuttgart 1979

[26] HARRIS, W. S., C. D. SCHOENFELD, A. M. WEISSLER: Effects of adrenergic receptor activation and blockade on the systolic pre-ejection period, heart rate J. Clin. Invest. 46 (1967) 1704

[27] HON, E. H., Y. MURATA, B. ZANINI, C. B. MARTIN, D. E. LEWIS: Continuous microfilm display of the electrochemical intervals of the cardiac cycle. Obstet. and Gynec. 43 (1974) 722

[28] HUCH, A., R. HUCH, K. MEINZER, D. W. LÜBBERS: Eine schnelle beheizte Pt-Oberflächenelektrode zur kontinuierlichen Überwachung des pO_2 beim Menschen. Elektrodenaufbau und Eigenschaften. Medizin-Technik, Stuttgart 1972

[29] HUCH, A., R. HUCH: Klinische und physiologische Aspekte der transcutanen Sauerstoffdruckmessung in der Perinatalmedizin. Z. Geburtsh. u. Perinat. 179 (1975) 235

[30] HUCH, A., R. HUCH, H. SCHNEIDER, G. ROOTH: Ergebnisse der transkutanen pO_2-Messung am Feten sub partu. In: SCHMIDT, E., J. W. DUDENHAUSEN (Eds.): Perinatale Medizin, Thieme, Stuttgart 1978
[31] JONES, C. T., R. D. ROBINSON: Plasma catechlamines in foetal and adult sheep. J. Physiol. 248 (1975) 15
[32] KELLY, J. V.: The fetal heart: Comparison of its electrical an mechanical events. Am. J. Obstet. Gynec. 91 (1965) 1133
[33] KLÖCK, F. K., TH. BÄRTLING, B. LIEDTKE: Die PEP-Zeit im Rahmen der intrapartalen Überwachung. In: SCHMIDT, E., J. W. DUDENHAUSEN, E. SALING (Eds.): Perinatale Medizin, Bd. VII. Thieme, Stuttgart 1978
[34] KLÖCK, F. K., TH. BÄRTLING: The pre-ejection-period of the human fetal heart: Significance of base-line alterations in Perinatal period. 6th European Congr. Perinat. Med. Vienna (A) 1978
[35] MARTIN, CH. B. jr.: Stress pre-ejection period n the fetal cardiac cycle. Obstet. Gyn. News (1975) 20
[36] MENDEZ-BAUER, C., A. RUIZ CANSECO, M. ANDUJAR RUIZ, A. MENENDEZ, J. ARROYO, R. D. GARDI, V. SASTRY, J. ZAMARRIEGO CRESPO: Early decelerations of the fetal heart rate from occlusion of the umbilical cord. J. Perinat. Med. 6 (1978) 69
[37] MORGENSTERN, J., H. CZERNY, H. SCHMIDT, J. SCHULZ, K. WERNICKE: Systolic time intervals of the fetal cardiac cycle. J. Perinat. Med. 6 (1978) 173
[38] MURATA, Y., T. IKENOUE, C. B. MARTIN: Pre-ejection phase of the cardiac cycle as an indicator of fetal condition during the antepartum period. Gynecol. Invest. 2 (1972) 26
[39] MURATA, Y., C. B. MARTIN: Systolic time intervals of the fetal cardiac cycle. Obstet. and Gynec. 44 (1974) 224
[40] MURATA, Y., C. B. MARTIN, R. H. PETRIE: Cardiac systolic time intervals in fetal monkeys. Gynecol. Invest. 5 (1974) 32
[41] MURATA, Y., K. MIYAKE, E. J. QUILLIGAN, C. B. MARTIN: The pre-ejection period of cardiac cycles in fetal lambs. Gynecol. Invest. 6 (1976) 107
[42] MURATA, Y., C. B. MARTIN, K. MIYAKE, T. IKENOUE: Systolic time intervals of cardiac cycle in fetal rhesus monkeys – Ventricular ejection time. Gynecol. Invest. 6 (1976) 107
[43] MURATA, Y., P. SCHMIDT, K. MIYAKE, P. S. LU, C. B. MARTIN: The pre-ejection phase of the fetal cardiac cycle in diabetic patients: Antepartum evaluation. Gynecol. Invest 6 (1976) 108
[44] MURATA, Y., C. B. MARTIN JR., T. IKENOUE, R. H. PETRIE: Cardiac systolic time intervals in fetal monkeys: Pre-ejection-period, Amer. J. Obstet. Gynec. 132 (1978) 285
[45] MURATA, Y., K. MIYAKE, E. QUILLIGAN: Pre-ejection period of cardiac cycles in fetal lamb. Amer. J. Obstet. Gynec. 133 (1979) 509
[46] ORGAN, L. W., A. BERNSTEIN, I. H. ROWE, K. C. SMITH: The pre-ejection-period of the fetal heart: Detection during labor with Doppler-ultrasound. Amer. J. Obstet. Gynec. 115 (1973) 369
[47] ORGAN, L. W., J. E. MILLIGAN, J. W. GOODWIN, M. J. BAIN: The pre-ejection-period of the fetal heart: Response to stress in the term fetal lamb. Amer. J. Obstet. Gynec. 115 (1973) 377
[48] ORGAN, L. W., A. BERNSTEIN, K. C. SMITH, I. H. ROWE: The pre-ejection-period of the fetal heart: Patterns of change during labor. Amer. J. Obstet. Gynec. 120 (1974) 49
[49] PAUL, W., E. QUILLIGAN, T. MACLACHIAN: Cardiovascular phenomenon associated with fetal head compression. Amer. J. Obstet. Gynec. 90 (1964) 824
[50] PERSIANINOV, L. S., I. V. ILYIN, V. L. KARPMAN, G. M. SAVELIEVA: The dynamics of the fetal cardiac activity. Amer. J. Obstet. Gynec. 94 (1966) 367
[51] PÜTZ, TH., O. ULLRICH: Ergebnisse fetaler Herztonkurven mittels Zeitlupenaufnahmen und pränataler Elektrokardiographie. Zbl. Gynäk. 66 (1942) 705
[52] SCHMIDT, H., H. CZERNY, J. MORGENSTERN, J. SCHULZ, K. WERNICKE: Verläufe der Pre-ejection-period bei fetalen Decelerationen. Tierexperimentelle Untersuchungen an Schafsfeten. In: SCHMIDT, E., J. W. DUDENHAUSEN (Eds.): Perinatale Medizin, Bd. VII. Thieme, Stuttgart 1978
[53] SCHULZ, J. K. WERNICKE, H. CZERNY, J. MORGENSTERN, H. SCHMIDT: Beitrag zur Pathophysiologie der Nabelschnurkompression. Verlauf der PEP, Schlagvolumen, Gefäßwiderstand. Experimentelle Untersuchungen an Schafsfeten. In: SCHMIDT, E., J. W. DUDENHAUSEN (Eds.): Perinatale Medizin, Bd. VII. Thieme, Stuttgart 1978
[54] WOLFSON, R. N., I. E. ZADAR, S. K. PILLAY, I. E. TIMOR-TRITSCH, R. H. HERTZ: Antenatal investigation of human fetal systolic time intervals. Amer. J. Obstet. Gynec. 129 (1977) 203

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